

Metadata of the chapter that will be visualized online

Chapter Title	Broadening STEAM Education Through Cross-Curricular Collaboration: The Case of Argumentation in Science and Religious Education	
Copyright Year	2024	
Copyright Holder	The Author(s), under exclusive license to Springer Nature Switzerland AG	
Corresponding Author	Family Name	Erduran
	Particle	
	Given Name	Sibel
	Suffix	
	Division	Department of Education
	Organization/University	University of Oxford
	Address	Oxford, UK
	Email	Sibel.Erduran@education.ox.ac.uk
Author	Family Name	Guilfoyle
	Particle	
	Given Name	Liam
	Suffix	
	Division	Department of Education
	Organization/University	University of Oxford
	Address	Oxford, UK
	Email	liam.guilfoyle@education.ox.ac.uk
Author	Family Name	Park
	Particle	
	Given Name	Wonyong
	Suffix	
	Division	Southampton Education School
	Organization/University	University of Southampton
	Address	Southampton, UK
	Email	w.park@soton.ac.uk

Abstract

Although there has been increasing research and development efforts in the integration of science, technology, engineering and mathematics (STEM) as well as the integration of STEM with the arts (i.e. STEAM), little attention has been placed on how other school subjects such as religious education (RE) can be integrated. In some countries like England, RE is a subject taught in secondary schools. It is a subject that aims to provide students with an overview of world religions and worldviews from a range of perspectives including philosophy and ethics. While RE and STEAM may seem mutually exclusive, there are common features addressed in both. For example, the articulation of arguments—or justification of claims with reasons and evidence—is widespread not only in science but also in RE. As such, it involves deep exploration of justification of why particular people hold the beliefs that they do. Furthermore, both RE and STEAM are, by definition, interdisciplinary and lend themselves to synthesis of new perspectives. Argumentation defined as the justification of knowledge claims with evidence and reasons, has emerged as a significant educational goal, advocated in international curricula and investigated through school-based research. Surprisingly, however, the contrast of argumentation in science and RE has been under-investigated although educators have been concerned with the manifestation of science-religion debates in schools, particularly in relation to topics such as evolution and intelligent design for numerous years. Considering the importance of worldviews in education, it is worthwhile to explore how RE might be related to STEAM education. The purpose of this chapter is to investigate how the scope of STEAM education can be broadened by focusing on school subjects conventionally not considered in relation to STEAM, such as RE. Considering RE itself is a vast domain, we focus on argumentation as an overarching theme where cross-subject integration and collaboration can be explored. Examples from the funded 3-year OARS Project from England are used to illustrate how cross-curricular collaboration between teachers can be enhanced.

Keywords (separated by “ - ”)

STEAM education - Religious education - Argumentation - OARS project

Chapter 12

Broadening STEAM Education Through Cross-Curricular Collaboration: The Case of Argumentation in Science and Religious Education

Sibel Erduran, Liam Guilfoyle, and Wonyong Park

Abstract Although there has been increasing research and development efforts in the integration of science, technology, engineering and mathematics (STEM) as well as the integration of STEM with the arts (i.e. STEAM), little attention has been placed on how other school subjects such as religious education (RE) can be integrated. In some countries like England, RE is a subject taught in secondary schools. It is a subject that aims to provide students with an overview of world religions and worldviews from a range of perspectives including philosophy and ethics. While RE and STEAM may seem mutually exclusive, there are common features addressed in both. For example, the articulation of arguments—or justification of claims with reasons and evidence—is widespread not only in science but also in RE. As such, it involves deep exploration of justification of why particular people hold the beliefs that they do. Furthermore, both RE and STEAM are, by definition, interdisciplinary and lend themselves to synthesis of new perspectives. Argumentation defined as the justification of knowledge claims with evidence and reasons, has emerged as a significant educational goal, advocated in international curricula and investigated through school-based research. Surprisingly, however, the contrast of argumentation in science and RE has been under-investigated although educators have been concerned with the manifestation of science-religion debates in schools, particularly in relation to topics such as evolution and intelligent design for numerous years. Considering the importance of worldviews in education, it is worthwhile to explore how RE might be related to STEAM education. The purpose of this chapter is to investigate how the scope of STEAM education can be broadened by focusing on school subjects conventionally not considered in relation to STEAM, such as

S. Erduran (✉) · L. Guilfoyle
Department of Education, University of Oxford, Oxford, UK
e-mail: Sibel.Erduran@education.ox.ac.uk; liam.guilfoyle@education.ox.ac.uk

W. Park
Southampton Education School, University of Southampton, Southampton, UK
e-mail: w.park@soton.ac.uk

© The Author(s), under exclusive license to Springer Nature

Switzerland AG 2024

Y. Li et al. (eds.), *Disciplinary and Interdisciplinary Education in STEM*,
Advances in STEM Education, https://doi.org/10.1007/978-3-031-52924-5_12

RE. Considering RE itself is a vast domain, we focus on argumentation as an overarching theme where cross-subject integration and collaboration can be explored. Examples from the funded 3-year OARS Project from England are used to illustrate how cross-curricular collaboration between teachers can be enhanced.

12.1 Introduction

The need for integrated approaches to curriculum and teaching is more urgent than ever, with the realisation that traditional subject-based teaching is insufficient for tackling the new challenges we are faced with in fast-changing society. In response, science, technology, engineering and mathematics (STEM) has risen as an approach to education and now it is further expanding its boundary to include ‘arts’ under the new banner of science, technology, engineering, arts and mathematics (STEAM) education. STEAM, as with STEM, has been initially put forward based on economic arguments, particularly on its value for serving the changing needs of employers and industries. In one report by UK Cultural Learning Alliance and Nesta (2017), STEAM is described as ‘essential for creating a workforce’ as well as for innovation, productivity, thus producing ‘a highly skilled and talented workforce’ that can serve ‘our hugely successful creative industries’ (pp. 1–3). Although STEM inherently captures the notion of creativity (e.g. STEM professionals need to be creative in order to produce new solutions to problems), STEAM accounts provide a further dimension to such themes as creativity. For example, STEM professionals may be inspired by visual representations produced by artists and adapt them in their work including in representation of models. However, there are other potential benefits of broadening STEM into STEAM including the incorporation of different worldviews (White, 2004) and citizenship goals (e.g. DeBoer, 1991).

In order to understand the place of STEAM in formal education, it is important to consider the broader context of national education systems. In the context of the United Kingdom, for instance, most pupils take only three to four subjects between the ages 16 and 18. The narrow subject focus in upper secondary education entails a systematic neglect of the arts and humanities subjects and in turn of the opportunities for integration of arts and STEM subjects (Nesta, 2014). Several initiatives have been put forward in the past decade in order to draw attention at a more balanced subject representation in the curriculum. In 2015, the British Educational Research Association commissioned a report on the directions for research in response to the changing nature of education across the United Kingdom, where STEAM was highlighted as the key to creative pedagogies for the twenty-first-century learning (Colucci-Gray et al., 2017). Similarly, the 2013 report by the UK House of Commons Culture, Media and Sports Committee had stated that “the crucial role of arts subjects in a modern education should be recognised and that art subjects should be added to the STEM subjects, changing STEM to STEAM” (p. 43). In many other parts of the world, similar calls have been made, as exemplified in various chapters of this book.

We begin the chapter by presenting STEAM as a research and curriculum agenda. Subsequently, we explore how religious education (RE) as a school subject may be situated within STEAM and indeed what might be a common thread among the respective disciplines underpinning STEAM that warrants the school subjects to be considered in unison. Argumentation is considered as a cross-cutting theme that can serve as a common thread. Argumentation is defined as the justification of claims with reasons and evidence (Toulmin, 1958). Argumentation defined as such can be considered an inherent aspect of different school subjects such as science, mathematics and RE. Our aim, then, is twofold: (a) to articulate the affordances of argumentation for STEAM education in general, and (b) to explore potential links of RE within STEAM education in order to broaden the scope of STEAM. The ultimate purpose is to establish a more holistic and coherent framework for school curricula across subjects linked across with coherent themes such as argumentation. The discussion begins with background on RE, particularly in the English context, and then proceeds to situating RE in STEAM. Our account is mainly theoretical in nature which can be supplemented with reference to some empirical school-based research. Hence, the final section will refer to a funded project that aimed to promote collaboration of science and RE teachers in the context of infusing argumentation in their lessons. The project will provide a concrete example of how RE can be situated within the STEAM agenda.

12.2 STEAM as a Research and Curriculum Agenda

Despite the flourishing discussion on and implementation of STEAM across the world, there is little agreement on the exact boundaries of STEAM education. In particular, the scope of ‘A’ remains vague (Colucci-Gray et al., 2017). Some stakeholders limit the ‘A’ to the narrow meaning of art (i.e., visual arts) (e.g., NAEA, 2017), while others add performing arts such as music and dance, and literary arts (e.g., Creative Industries Federation, 2015; Haroutounian, 2019). In these views, STEM subjects tend to be taken as being opposite to the arts by having objective, logical characteristics and pursuing practical values, contrary to the arts with subjective, imaginative and intuitive enterprise (Haroutounian, 2019). Some researchers go even further to take it as encompassing broader humanities (e.g., Lewis, 2015; Yakman & Lee, 2012). This view is well illustrated in the framework of STEAM education by Yakman and Lee (2012), where the various branches of STEM disciplines as well as those of humanities and social sciences are integrated for holistic and lifelong education. Such arguments for integration are gaining increasing attention in parallel with recent educational theories such as curriculum integration (Beane, 1997) as well as with the changing landscape of knowledge production where collaboration across science, engineering, social science and humanities is emphasised and encouraged (NAS et al., 2005).

This broad meaning of ‘arts’ is also found in the names of university divisions such as ‘College of Arts and Sciences’ and degree titles such as ‘Bachelor of Arts’.

In a similar fashion, Ge et al. (2015) also defined STEAM as “the inclusion of the liberal arts and humanities in STEM education; some STEAM conceptions simply use the ‘A’ to indicate a fifth discipline area—namely, arts and humanities”. Lewis (2015) problematises the current STEAM paradigms that position arts and humanities as mere ‘enhancements’ to core STEM knowledge, and instead take STEAM as a form of tradition in liberal arts education. She suggests that STEAM naturally promotes using multiple, iterative and collaborative approaches to problem-solving within a complex learning environment (Lewis, 2015). Such broadening conception of ‘A’ is in parallel with the recent criticism of neoliberal paradigm of education that prioritises the economic values over more intrinsic, humanistic aims of education (Biesta, 2015; Nussbaum, 2010).

The emphasis of the arts is also visible in recent perspectives on STEM education that goes beyond arguments about economic growth and attend to the fundamental purposes of teaching STEM such as social inclusion, democracy and sustainability (Chesky & Wolfmeyer, 2015; Colucci-Gray et al., 2019). Consider, for example, Bybee’s (2010) conceptualisation of STEM literacy with the following four components:

- Acquiring scientific, technological, engineering, and mathematical knowledge and using that knowledge to identify issues, acquire new knowledge, and apply the knowledge to STEM-related issues.
- Understanding the characteristic features of STEM disciplines as forms of human endeavours that include the processes of inquiry, design, and analysis.
- Recognising how STEM disciplines shape our material, intellectual, and cultural world.
- Engaging in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as concerned, affective, and constructive citizens. (p. 31)

These capacities, particularly the second to fourth items, clearly indicate that STEM literacy does not only consist in content knowledge of STEM, but also the humanistic foundations and contexts that underpin the STEM enterprises. In other words, humanities and arts are not separate from STEM, but instead are embedded in diverse aspects of STEM. This means that for the purpose of STEM education to be fully achieved, relevant humanistic aspects must be addressed alongside (Park et al., 2020a). An area of research related to the societal context of STEM is what is often referred to as “socioscientific issues” (SSI). Recognising the inherent, inevitable association of science and values, SSI researchers have underscored the importance of infusing moral and social values into science education (Sadler et al., 2006). Such movement is particularly evident as science educators began to engage in responding to recent environmental challenges such as climate change (Sharma, 2012), and also in promoting social justice through STEM education (Bencze, 2017; Erduran & Kaya, 2016; Yacoubian & Hansson, 2020). These initiatives highlight that interdisciplinary thinking across STEM and humanities is essential to tackling the global problems such as global warming, the Covid-19 pandemic, and the misuse of science by political figures and mass media in times of such events.

It should also be noted that while arguments for STEM education have now become mainstream, the precise ‘nature’ of STEM itself needs further articulation. Is nature of STEM a combination of nature of distinct disciplines or is there an emergent characterisation of STEM? While such fundamental questions are important, it is beyond the scope of this chapter to address them. A recent special issue of the journal *Science & Education* (Erduran, 2020a) presents several theoretical and empirical investigations to address such questions which can also be extended to “nature of STEAM”. Here we narrow down our discussion by returning to the explication of STEM education by exploring how it may relate to conventionally under-emphasised school subjects. Although it is encouraging to witness the promotion of STEAM through infusion into STEM visual arts and humanities subjects, there is still work to be done in linking other school subjects that may have been ignored in the STEM-STEAM equation. For example, in England RE is a school subject that is rarely integrated into STEM projects or referenced in STEAM discussions. The term ‘religious education’ may invoke a range of ideas in the minds of readers who come from different cultures and contexts or who may have different experiences of religious education from their own schooling. For example, RE might invoke impressions of long-standing debates about evolution versus creationism (e.g. Thagard & Finlay, 2010) or particular stereotypes about science and religion (e.g. Mansour, 2015).

In the rest of the paper, we will explore how RE may be situated within STEAM and indeed what might be a common thread among the respective disciplines underpinning STEAM that warrants the school subjects to be considered in unison. The cross-cutting theme that can serve as a common thread will be referred to as ‘argumentation’ or the justification of claims with reasons and evidence (Toulmin, 1958). Argumentation defined as such can be considered an inherent aspect of different school subjects such as science, mathematics and RE. Our aim, then, is twofold: (a) to articulate the affordances of argumentation for STEAM education and (b) to explore potential links of RE to STEAM in order to broaden the scope of STEAM and to be inclusive of different school subjects that are conventionally excluded. The ultimate purpose is to establish a more holistic and coherent framework for school curricula across subjects linked with coherent themes such as argumentation. The discussion begins with background on RE, particularly in the English context, and then proceeds to situating RE in STEAM. Empirical data are presented from a funded research project that aimed to promote collaboration of science and RE teachers in the context of infusing argumentation in their lessons. Data provide a concrete illustration of how science and RE teachers, as example cohorts within the STEAM education workforce, regard cross-curricular collaboration.

12.3 Religious Education: A Potential Component of STEAM Education?

The interface of science and religion has been extensively studied in the educational research literature, for example in the context of evolution versus creationism debate (e.g. Basel et al., 2014) and teachers' conceptions about particular topics relevant to the science-religion debate (e.g. Castéra & Clément, 2014). Furthermore, there is research on science teachers' views about the science and religion comparison (e.g. BouJaude et al., 2011; Mansour, 2015). However, very few studies involved both science and RE teachers in the same study (e.g. McKinney et al., 2014). It is important, from an early stage, to explain what is meant by "religious education" (RE). Considering the relative emphasis of STEM and STEAM education in the research community contributing to this book, RE is likely to be an unfamiliar topic. Hence, we refer to nature of RE as a school subject, including the aims and presentation in curriculum or policy documents. In particular, we will draw on international literature though we are particularly informed by religious education (RE) in our current context, England. Two essential points need to be stated to foreground our later arguments. First is to recognise that RE is present in many school contexts as a subject in some form or another and therefore represents an opportunity for learning that is connected with the rest of the school curriculum. The second is that the form of RE that we are referring to within our overarching argument is one that is diverse and pluralistic rather than an inculcation into a faith.

Religious Education across various countries can be "bewilderingly different" and specific to national contexts (Fancourt, 2013, p. 193), but it is still that case in many countries RE is more than an optional subject of study and its provision is mandated by legal frameworks (Schreiner, 2009). There are many contexts in which RE takes the form of an impartial study of religious and non-religious perspectives, rather than inculcation into a faith (Jawoniyi, 2015). This is, broadly speaking, the sort of RE that we see within the English school context (Fancourt, 2013). England is not unique in the international landscape of RE provision in this respect but can serve as a good example of the sort of RE that we are relating to STEM/STEAM in this chapter.

In the case of England, there have been, and continue to be, multiple voices at play in the development of RE policy (Fancourt, 2015). Decision making in RE curriculum is a highly contested and political space (Freathy et al., 2017). Over time, the nature and terminology of RE has changed in England. In the time of the Education Act of 1944, it would have been referred to as "Religious Instruction" in Christianity but evolved to study of diverse religious and non-religious worldviews by the time of the Education Reform Act in 1988. From then until now, the terminology of "Religious Education" has generally been used. Under this umbrella, however, there has been a changing focus towards more pluralistic approaches and a rejection of theology as the primary mode of RE—with perhaps the exception of faith schools (Cush, 1999). The subject of RE has instead drawn on other disciplines and areas of study in its approach, including philosophy (Hookway, 2002; Hella &

Wright, 2009), religious studies (Smart, 1989) or social studies more broadly (Jackson, 1997). Therefore, other terms emerged for this study in schools depending on these disciplinary perspectives, such as “Religious Studies” or “Philosophy and Ethics”. This rejection of the utility of theology as a disciplinary approach and other such changes in the RE landscape continue to be contested and reappraised (Reed et al., 2013; Freathy & John, 2019). In consideration of future directions of RE, the Commission on Religious Education (CoRE) Report of 2018 called for new terminology for the subject such as “Religion and Worldviews” to acknowledge a “*new and richer version of the subject... drawn from the academic study of religious and non-religious worldviews as well as broader social changes in England and globally*” (2018, p. 3). The expression of RE in these terms explicitly expands the boundaries of the subject, where worldviews can include non-religious belief systems. It is not to say non-religious beliefs systems were not considered before, but Hannam and Biesta (2019) argue that “it puts religion in the wider context of world views, and thus potentially offers a broader framing for the subject than an exclusive focus on religion or religious world views would do” (p. 56).

Shifts in these terms, and others, signify shifts in thinking about the purpose of RE. They appear to capture a continued trend towards the pluralistic values of respect, tolerance, and appreciation of diverse beliefs. The aims are about understanding of one’s own and others’ beliefs or stances, and about developing an ability to articulate these understandings effectively (CoRE, 2018). There is an acknowledgement that religious and non-religious worldviews will always play a key role in public discourse on a wide range of topics including social justice, human rights, sustainability, and many others. In order to live and work together successfully, people need to understand each other and the worldviews that they bring to that discourse. Hannam and Biesta (2019) further argue (though critically) that the framing of RE as the study of worldviews suggests that individuals are sense-making and meaning-making beings and highlights how religious and non-religious worldviews play a role in the sense- or meaning-making. In this way, RE becomes a subject to explore a multiplicity of ways of understanding the world. Freathy and John (2019) discuss the possibility of the presence of “Big ideas” in the Study of Religion and Worldviews (SORW) in ways that are analogous to the Big Ideas of Science Education (Harlen, 2015). These are as follows:

- Encountering religion(s) and worldview(s): Contested definitions and contexts
- Encountering Oneself: Reflexivity, Reflectivity and Positionality
- Encountering Methodologies and Methods: Discernment and Diversity
- Encountering the ‘Real World’: Relevance and Transferability.

This vision of RE (or SORW) is one which foregrounds the multiplicity of epistemologies, methodologies, theories, concepts, skills, and subject matter present in the cognate disciplines of RE including philosophy, theology and sociology (Freathy et al., 2017; Freathy & John, 2019). Recent analysis of current RE curricula in England reveals apparent goals of expression of personal views with democratic goals, deeper epistemic understanding of different disciplinary perspectives, and the ability to soundly support one’s own positionality while also engaging with the

positions of others (Chan et al., 2020). Religious education motivated by pluralistic values is not unique to England. Similar *raisons d'être* for RE have been noted across Western Europe (Jawoniyi, 2015). Thus, RE underpinned by pluralistic approaches presents potential opportunities to explore and connect across multiple other subjects within the curriculum irrespective of the national context.

12.4 Contributions of RE to STEAM Education

Building on the significance of the integration of science, technology, engineering and mathematics with other disciplines such as the visual arts, this section explores how RE as a school subject framed from the national context of England could be positioned in wider context of STEAM, particularly with regard to the relationship between RE and science. From a STEAM education perspective, RE has many interesting features that could be linked with other subjects. An extended discussion can potentially explore the synergies as well as inherent differences between the two subjects in terms of curriculum goals, skills and competencies, intersecting curriculum topics, and pedagogical approaches. In this section, a few of such instances are visited in order to provide a broad overview of potential overlap between RE and STEAM, particularly science.

Worldviews Both science and RE are concerned with worldviews, which are “a set of fundamental beliefs, values, etc., determining or constituting a comprehensive outlook on the world; a perspective on life” (Oxford University Press, n.d.). Just as different religions hinge on different views about the world, the scientific community commits to a certain set of values about what makes a researchable problem, reliable methods and worthwhile findings—together constituting a ‘paradigm’ for research (Kuhn, 1962). Giannetto (2009) illustrated this by interpreting relativity theory in terms of the conflict among different images of nature, God and their relationships with humans. In science, worldviews are also a chief curriculum goal, given the fundamental purpose of scientific activities to make sense of the natural objects and processes (Matthews, 2009). In RE, *A Curriculum Framework for Religious Education in England* (REC, 2013) states as one of its aim that Key Stage 3 (ages 11–14) students should ‘know about and understand a range of religions and worldviews’ (p. 11). Such an acknowledgement led to the recent announcement of the statutory change of the subject name from RE to ‘Religion and Worldviews’ (CoRE, 2018). RE curricula are aimed at promoting students’ understanding of the multiplicity of religions and worldviews, how they relate to culture, society and politics, and also encourages students to develop their own worldviews (White, 2004; Wright, 1993).

Citizenship It has been a core intersecting aim of science and RE to cultivate future citizens who can understand, use and communicate arguments based on beliefs and/or evidence. The transition in the fundamental goal of science education from

training STEM professionals to cultivating scientifically literate citizens occurred throughout the twentieth century (DeBoer, 1991). As a result, most science education curriculum and vision documents today clearly state their aim to serve promoting social justice through cultivating citizenship of individuals (AAAS, 1989; OECD, 2020; NGSS Lead States, 2013; Royal Society Science Policy Centre, 2014). Scientific literacy is defined as ‘the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen’ (OECD, 2017, p. 22). Similarly, the central goal of RE in England during the past three decades has been centred on achieving *religious literacy* (Hannam et al., 2020), which constitutes a core quality of responsible citizens living in multi-religious, multi-cultural and post-secular society. The citizenship aims of science and RE is becoming particularly important given the rise of interests in environmental justice and biopolitics in STEAM education (Bazzul, 2016; Carter et al., 2017), which necessarily involves the interplay of science, society and human lives. Scientific reasoning can potentially facilitate the establishment of democratic participation in society (Erduran & Kaya, 2016).

Reasoning and Argumentation Students’ reasoning and argumentation skills are a central concern in both science and RE (Chan et al., 2020). For example, the National Curriculum for Science in England suggests that students should experience “making decisions based on the evaluation of evidence and arguments” (DfE, 2015, p. 57). An English RE curriculum document states that students should develop ‘widely informed and detailed arguments about beliefs, ethics, values and issues, drawing well substantiated conclusions’ (Lambeth, 2015, p. 21). One example that shows how infusing the RE perspective can enrich argumentation in science comes from the different types of claim and evidence. Studies have reported that students tend to identify religious content as ‘just opinion’ as opposed to scientific knowledge based on solid evidence (Cooling, 2012; Easton, 2019). These ‘opinions’ sometimes may not be based on empirical grounds but on the authorities such as the bible. Students can be asked in RE to not only “learn about sacred texts” but also to “consider their meanings and interpretation” (Lambeth, 2015, p. 12) or to consider “different sources of authority and how they inform people’s beliefs, values and action” (Norfolk, 2012, p. 43). In addition, scientists usually make factual and descriptive claims, whereas religious claims tend to be normative and prescriptive. Such simplistic divide between scientific argumentation as fact-based and religious argumentation as opinion-based can be problematic given many decisions in one’s individual and social life necessarily may involve both types of reasoning.

Critical Thinking Within the growing international movements focusing on skills, there is increasing emphasis on preparation for a rapidly changing world that is characterised by digital societies and knowledge economies. Within this framework, skills such as critical thinking is positioned as being essential by educators, business leaders, academics and governmental agencies alike. For instance, the OECD has been advocating the importance of critical thinking in contemporary societies glob-

ally (OECD, 2019). Critical thinking is often considered to include mental processes, strategies and representations that are needed to solve problems and make decisions:

Critical thinking is the use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned, and goal directed—the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions, when the thinker is using skills that are thoughtful and effective for the particular context and type of thinking task (Halpern, 2014, p.8).

Defined as such, critical thinking is a mode of thinking that can apply not only to science and RE but more broadly in practically all school subjects. The particular differences across school subjects in terms of how critical thinking is instantiated might exist for instance, between history, art, music, science, mathematics, technological studies and vocational studies (Bailin et al., 1999).

Curriculum Topics Many problems in contemporary society require decisions that involve disciplinary knowledge of STEM as well as social and ethical considerations, collectively amounting to questions for STEAM. Yet, analyses of numerous curricula from around the world illustrate a significant deficit in relation to content focusing on the social-institutional aspects of science (Park et al., 2020a). For example, science curriculum documents from Turkey (Kaya & Erduran, 2016), Taiwan (Yeh et al., 2019) and Ireland (Erduran & Dagher, 2014) as well as science textbooks from South Korea (Park et al., 2020b) and Australia (MacDonald, 2017) place minimal emphasis on the social context of science. The current Covid-19 pandemic is a case in point for why it is important to broaden the curriculum to present science in context. Erduran (2020b) argues that science (e.g. virus, models) and mathematics (e.g. graphs, probability) are very directly linked to the pandemic. However, social sciences such economics (e.g. risk, cost-benefit) and sociology (e.g. ethnicity) are also fairly closely associated with how the pandemic needs to be addressed. Indeed, the Covid-19 pandemic is an example that demonstrates how cross-curricular meaning-making is essential. Erduran (2020b) illustrates how comparing the Covid-19 pandemic to past pandemics (i.e. history), dealing with the grief of losing loved ones and seeking meaning in the tragedy (i.e. religious education), using technology for production of PPE, work, learning and family (i.e. computer and information technology) are some illustrations of science as situated in a complex array of contemporary issues. School curriculum topics, then, can be examined in a coherent manner across different school subjects in order to maximise students' understanding of complex societal problems.

Pedagogy It has been argued that teachers' ability to promote and facilitate class discussions on controversial issues is essential in socially relevant education (Levinson, 2006; Hand & Levinson, 2012). However, science teachers have been found to experience problems with enacting student-centred lessons when addressing issues with social and ethical aspects (Bossér et al., 2015), and also using pedagogical techniques in dealing with sensitive and controversial topics (Ratcliffe & Millar, 2009). These difficulties indicate that the pedagogical skills and methods for

science are often insufficient to be applied for teaching SSIs and environmental issues that are of rising societal importance. It is in this sense that examining how RE teachers and researchers approach such issues can enrich STEM teaching and learning, given that plurality, diversity and controversy are at the heart of post-secular RE (Jackson, 2004; Skeie, 2009). For example, Erduran et al. (2020) study with teachers in England found that RE teachers use pedagogical strategies such as group discussion, debate and valuing different positions more frequently than science teachers. By dialoguing with pedagogical approaches across school subjects, theories and practices in STEM education can potentially improve in addressing urgent issues of our time.

The preceding discussion has provided a rationale for how RE can be considered in relation to STEM and STEAM education broadly and science in particular. Curriculum goals such as critical thinking skills; competencies such as argumentation or evidence-based reasoning; cross-curricular topics such as the current Covid-19 pandemic; and pedagogical approaches such as group discussions all point to why it is important to consider RE in STEAM education discussions. There may be many other instances of overlap for cross-curricular themes in broadening of the STEAM agenda (e.g. problem-solving, socio-scientific issues). We will focus on argumentation because this is an area where our team has been pursuing school-based research and development in order to broaden teachers' and students' experiences with STEAM related issues. We can thus provide some empirical insight along with theoretical arguments for how RE can contribute to the STEAM agenda. In the next section, then, we focus on argumentation as a cross-cutting theme in order to illustrate cross-disciplinary links between RE and STEAM.

12.5 Argumentation: A Cross-Cutting Theme for Cross-Disciplinary Links in RE and STEAM Education

Characterisation of 'argumentation' as the justification of claims with evidence and reasons is fairly common. Often, the underpinning theoretical construct is Toulmin's (1958) argumentation model which has been widely used as a methodological tool for analysing argumentation in science education (e.g. Erduran et al., 2004; Jimenez-Aleixandre et al., 2000). For example, Toulmin's argumentation pattern (TAP) enabled researchers to do quantitative analyses of classroom discourse in terms of the statistical comparison of TAP cluster frequencies in terms of claims, data, warrants, backings and rebuttals (Erduran et al., 2004). Another methodological tool for analysing arguments is the use of Walton's (1996) argumentation schemes for presumptive reasoning. Walton (2001) explained the nature of presumptive reasoning as follows:

It is merely a presumption, as opposed to a proved fact. A presumption then is something you move ahead with, for practical purposes, even though it is not known to be true at the

present time. It is a kind of useful assumption that can be justified on practical grounds, in order to take action, for example, even though the evidence to support it may be insufficient or inconclusive. Presumption and plausibility are both concerned with the practical need to take action, or to provisionally accept a hypothesis, even though the evidence is, at present, not sufficient to prove the hypothesis beyond doubt, or show it is known to be true (p. 155).

Furthermore, Walton states that the justification for presumptive reasoning is that “despite its uncertain and inconclusive nature, it moves a dialogue forward part way to drawing a final conclusion, even in the absence of evidence for proof at a given point” (Walton, 2001, p. 156). Both Toulmin’s and Walton’s frameworks can potentially apply in various ways to characterising argumentation in science, RE and more widely in STEAM education.

Science, technology, engineering and mathematics are distinct disciplines in their own right and have differing sets of aims and practices (Park et al., 2020a, b). However, there may be several aspects of these domains that span them, such as the use of argumentation. Professionals in STEM disciplines would all be engaged in particular forms of reasoning that demand the consideration of reasons and evidence. Whether the issue is about design of flood drainage systems, production of renewable energy or building earthquake resistant structures, STEAM professionals are in a position to propose solutions and justify these solutions with credible evidence and reliable strategies to problem solving. In other words, argumentation as defined by evidence-based reasoning or justification of knowledge claims (Toulmin, 1958) with reasons and evidence underpins reasoning in STEM. In this sense, it can be considered a cross-cutting theme that is an inherent aspect of reasoning in STEAM disciplines.

Although argumentation can be a cross-cutting theme, it should also be highlighted that there may also be specific aspects of arguments as they are instantiated in a particular discipline. For example, in the case of science and mathematics, there are different accounts of framing of arguments. In the case of mathematical arguments, are typically discussed as proof strategies (Pedemonte, 2007) and deductive inferences (Aliseda, 2003). Argumentation in mathematics may also be characterised in terms of persuasive discussion (Zack & Graves, 2001). In the case of science, there can be claims about a range of issues including not only scientific knowledge but also the processes by which scientific knowledge is generated. Similarly, in the case of mathematics, technology and engineering claims can be made about a particular mathematical equation, an approach to industrial design and the suitability of digital technologies in solving particular problems. For example, many contemporary global problems such as the Covid-19 pandemic and issues of sustainability and environmental protection are underpinned by arguments to justify how to address these complex problems from a multitude of perspectives. Hence, there is a need for both research and professional development to support the integration of argumentation across and between STEAM subjects/disciplines.

The Oxford Argumentation in Religion and Science (OARS) project is an example of such ongoing professional development and research. In the next section, we provide a brief account of this project and offer some insights into the value that can be gained from research and development efforts that focus on common goals across

the STEAM agenda and the wider school curriculum. The project focuses on science and religious education. Although the project is inclusive of STEAM themes in relation to lesson activities, the participants in the project are science and RE teachers. The choice of focus on science teachers was due to logistic in accommodating the scale and funding aspects of the project. It is possible that a subsequent project could be designed to extend the model of professional development in the project to include cohorts of mathematics, technology and engineering. In the next sections, we provide an overview of the project and present some empirical data on how science and RE teachers viewed cross-subject collaboration.

12.6 Oxford Argumentation in Religion and Science Project

The 3-year-long OARS project is funded by the Templeton World Charity Foundation as part of the *Big Questions in Classrooms Initiative* and is based in the Department of Education at the University of Oxford (Chan & Erduran, 2023; Erduran et al., 2019, 2022; Godfrey & Erduran, 2021; Guilfoyle & Erduran, 2021; Park et al., 2022). The project is designed to work with pairs of RE and Science teachers from 15 schools to explore the possibilities for teaching argumentation at the interface of these two school subjects. The project involves structured collaborative professional development for teachers of both subjects and pre-post data collection with participating teachers and their students, to better understand the impact of the professional development. Although there are some examples of collaboration between science and RE teachers (e.g. McKinney et al., 2014), such collaboration tends to be fairly rare. Hence a broader goal of the project is to explore how traditionally disparate subjects in the school curricula can be brought together through the lived experiences of teachers through professional development.

The project is guided by the principle that argumentation can ultimately contribute to students’ critical thinking skills and situating argumentation as a common denominator across school subjects can begin to bring focus to the elusive notion of “critical thinking skills” that is included in many school curricula. As Baillin et al. (1999) argue,

Teaching critical thinking is best conceptualized not as a matter of teaching isolated abilities and dispositions, but rather as furthering the initiation of students into complex critical practices that embody value-commitments and require the sensitive use of a variety of intellectual resources in the exercise of good judgement (p. 299).

A six-session professional development programme was designed for participating teachers; the project is ongoing at the time of writing with four workshops completed to date. Due to the emergence of the Covid-19 pandemic, it was not possible to implement the remaining two workshops. Other limitations have involved the heavy workload of the teachers where they were not able to leave school for a larger chunk of time to attend the workshops at the university. While we recognise that this is a limitation in terms of recommendations for effective professional development

AU4

(Darling-Hammond et al., 2017), it is nevertheless a realistic and practical approach to working with in-service teachers. Teachers were recruited from local schools in pairs or sometimes groups. It was considered fundamental to the success of the project that teachers from both subjects would join the project together from the same school as the collaboration between these subject areas is a particular focus. Sessions lasted 1.5 h and were hosted in the University after school time. The professional development recognised that teachers were experienced practitioners with expertise to offer about the nature of their subject. The sessions focused on supporting students in learning how to make complex judgements in science, RE, and on issues where these subjects may overlap (Erduran, 2020).

Teachers worked together to examine the curricula of both subjects to understand not only the opportunity for argumentation within their own subject, but within the 'other' subject as well. This afforded teachers the chance to better understand their colleague's subject and to seek out areas of difference, similarity, overlap or complementarity. Teachers and researchers shared practice and discussed various pedagogical strategies for supporting argumentation within and across subjects. Together, teachers constructed plans for how they could collaborate to further student's abilities of argumentation in feasible ways within their specific school contexts. Some key principles, based on what is known about quality professional development (e.g. Garet et al., 2001; Darling-Hammond et al. 2009, 2017), guided the design and implementation of the professional development experience in the OARS project. First, collaboration was a fundamental component. Collaborative relationships were fostered (a) in the pairs or groups of teachers who were working together within schools, (b) among the cohort of teachers across all participating schools, and (c) between the teachers and the project team. There was an explicit recognition of distributed expertise (Childs et al., 2014), where everyone involved had something to offer, but also that each person was learning outside of their area of expertise because of the interdisciplinary nature of the project.

A second core principle, then, was to establish a culture of charitable interpretation and not to take offence if someone misspoke outside their area of expertise. Such errors would be seen as a key element of the learning process and of building mutual understanding. Third, each session of the professional development was designed to relate to and reflect on teachers' own experiences, coherently follow up on previous learning, but also explicitly build in new learning on each occasion. Fourth, engagement needed to be manageable but sustained. During the interim periods between sessions, there were ongoing tasks on which teachers could collaborate. These were designed to be immediately applicable to practice and additional support was made available from the project team. Ideally, professional development should not add to teachers' workload (Hargreaves, 1994) and this ambition was a prominent design concern for OARS. We understood that the collaboration being advocated in the programme would not occur naturally and is therefore, by definition, an additional task for teachers. However, the programme modelled how these engagements could be mutually beneficial and might minimise other aspects of workload (for example, planning time could be reduced by sharing expertise and resources). Finally, an online community was utilised in an effort to

build and maintain a community (Lantz-Anderson et al., 2018), and to provide helpful resources that teachers could adapt or adopt.

12.7 Teachers’ Reflections About Cross-Curricular Collaboration in the OARS Project

Project OARS teachers were interviewed in order to develop some understanding of how they viewed the work of the project. Both science and RE teachers mentioned an array of issues in relation to cross-curricular collaboration. Table 12.1 illustrates some example data showing the value of cross-curricular research and development from teachers’ points of view. The themes raised by the teachers concern issues such as relevance for the curriculum, the broadening of the subject knowledge, the value of argumentation as a skill, the role of cross-subject teaching in enhancing students’ confidence and their own reflections illustrating how the project has impacted them as teachers. The teachers explained how the initial collaborative discussions facilitated in workshops were particularly useful in understanding the extent to which the subjects sought to address similar aims and addressed similar curriculum topics. Teachers specified the potential benefits that were emerging in terms of bringing coherence across a curriculum that was utilising similar skills in different subjects but with often different terminology. The value of cross-curricular work between science and RE was considered by the teachers who viewed such work as engaging students in a more holistic and realistic view of knowledge. That is to say, students could be to see that real-world problems are not often compartmentalised by subject area but require complex multifaceted understanding.

Teachers of both subjects, across multiple schools, agreed in that a goal of their collaboration would be to better equip students with confidence about their own position on issues or worldview. Both science and RE teachers were also motivated by the ambition to address and develop students’ capacities for critical thought and justification of knowledge claims. The skill of argumentation in multiple contexts was thought to be advantageous in terms of fostering students’ confidence to develop and support their own views. What is particularly illuminating in the teachers’ reflections on their initial collaborative engagement with the ‘other’ subject is that they stated how little they knew about their colleagues’ efforts to achieve the same goals. Teachers were often surprised by the extent to which the other subject was addressing similar skills or topics, and this opened their eyes to potential complementarity in their work.

These examples offer insight into the ways in which value can be gained from a focus on common goals across the STEAM agenda and the wider school curriculum, particularly in this case between the subjects of science and RE. They indicate that teachers, once put into professional collaboration on the topic of argumentation, saw clear synergies between the activities and goals of their respective subject. The teachers were able to identify clear benefits to working in more complementary

Table 12.1 Science and RE teachers' reflections about cross-subject collaboration

Theme	Example quotes	t1.1
Relevance for curriculum		t1.2
	<i>Because I think I haven't been exposed to that much cross curricular collaboration. But as soon as, think, from probably the first workshop, after we</i>	t1.3
	<i>discussed how argumentation can be used in science and in religion, I did actually</i>	t1.4
	<i>realize that there is a fair amount of,... there are cases in the science curriculum</i>	t1.5
	<i>where we discuss things to do with religious education or to do with history or</i>	t1.6
	<i>geography. And actually, I hadn't thought about it in terms of it being part of</i>	t1.7
	<i>other subject, because it was on the science curriculum. So, I think it has changed.</i>	t1.8
	<i>I think I have become much more aware there is a lot more overlap between the</i>	t1.9
	<i>science curriculum and other subjects than I actually think I originally thought.</i>	t1.10
	<i>(SchoolG-Science)</i>	t1.11
	<i>I think it's quite an exciting thing to do. I mean, certainly, I don't think we've ever</i>	t1.12
	<i>had any collaboration with science, which is strange to some degree, because</i>	t1.13
Holistic knowledge	<i>there is quite a lot of overlap. And children often say yes, but science has proved</i>	t1.14
	<i>all of this wrong. And they'll come out with it. They can't explain how. They'll go:</i>	t1.15
	<i>'But science has they know it has!' And if you ask for an example, they sort of</i>	t1.16
	<i>clam up. And I think it's quite interesting, because I suppose the traditional view</i>	t1.17
	<i>is they're quite different subjects. But it's quite exciting to sort of find where that</i>	t1.18
	<i>overlap is, and to see what collaboration we can have. (School B-RE)</i>	t1.19
	<i>It's getting them to understand that the, you know, that compartmentalization</i>	t1.20
	<i>knowledge isn't really a factor or a feature of the real world, is it sort of a</i>	t1.21
	<i>function of school timetables? (SchoolR-Science)</i>	t1.22
	<i>So, suppose the students are starting to see knowledge in a broader sense, rather</i>	t1.23
Importance of justifying claims	<i>than just compartmentalized. They start to see that subjects feed into each other.</i>	t1.24
	<i>(SchoolM-RE)</i>	t1.25
	<i>Does that evidence actually backup that claim? Because we get a lot of claims...</i>	t1.26
	<i>And that's a really valuable thing, I think, for students to take away from their</i>	t1.27
	<i>education, because then they're presented with a vast number of claims, and</i>	t1.28
	<i>mostly through social media, there's a huge number of completely invalid claims.</i>	t1.29
	<i>[RE: And irrelevant as well], supposedly, with evidence and yet it doesn't back it</i>	t1.30
	<i>up. So, students being able to pick out. (SchoolC-Science)</i>	t1.31
Enhancing student confidence	<i>And being able to see that the evidence that is being quoted is irrelevant to the</i>	t1.32
	<i>claim that is being made... that skill of spotting it, I think, is a skill. I think for a</i>	t1.33
	<i>lot of people they are just kind of nodding when they hear things. (SchoolC-RE)</i>	t1.34
	<i>So that would be my primary context... is to give people more confidence in being</i>	t1.35
	<i>able to articulate and self-articulate, articulate themselves, what they really</i>	t1.36
	<i>believe to be true. (School R- Science)</i>	t1.37
	<i>I'd want them to have the confidence because they have the skills to be able to do</i>	t1.38
	<i>that, to create an argument. A lot of them don't express opinions, because they</i>	t1.39
	<i>haven't been able to really formulate a judgment on anything (SchoolC-RE)</i>	t1.40
		t1.41

(continued)

Table 12.1 (continued)

Theme	Example quotes
t1.42 t1.43 t1.44 t1.45 t1.46 t1.47 t1.48 t1.49 t1.50 t1.51 t1.52 t1.53 t1.54	Reflecting on own learning <i>I think if nothing else, it's made me think harder, and see the possibilities of links between science and humanities in ways I might not have considered. And particularly with RE, it's not a subject that springs to mind as 'Oh, yes, there's a really close link there'. And yet the more discussions we have, the more I can see actually there's possibilities there. And that'd be great. Because it might go some way to overcoming that age old, sort of false contrast that things are either... there are scientific things, and there's religious things, and never the twain shall meet. (SchoolC- Science)</i> <i>For me, I think just in as much as what the workable links are, you know, it's not something I've ever really paid attention to. And then I think some of those links are, if you think about them, fairly straightforward, but I just never really spent a lot of time thinking about them. And therefore, I think it has really made me think about those opportunities. (SchoolC- RE)</i>

ways to achieve their common goals, and to bringing an enhanced coherence to students' school experience through more holistic cross-curricular approaches.

12.8 Conclusions and Discussion

In this chapter, we argued for the broadening of the scope of STEAM to include conventionally overlooked and understudied school subjects such as RE. First, we outlined STEAM as a research and development agenda, and illustrated how the inclusion of RE as a school subject is warranted within this agenda. Given the relative lack of emphasis on RE in STEM and STEAM efforts, we reviewed how RE can potentially be integrated into STEAM efforts and what the benefits of such inclusion might be. Having provided an overall rationale for the inclusion of RE in STEAM education, we then focused on one particular topic that can serve as a cross-cutting theme in STEAM education broadly and more specifically between science education and RE. In other words, we have illustrated the relevance of RE for STEAM education by focusing on how argumentation relates to both science education and RE. Having established a theoretical basis for the inclusion of RE in STEAM education in the context of argumentation, we then illustrated some empirical findings from a research project that aimed to foster cross-subject collaboration in RE and science education. The outcomes from teachers' collaboration suggested that teachers could see the benefit of including the other subject in their own lessons. This observation provides evidence for the utility of inclusion of RE in STEAM education efforts.

As the whole scope of this book illustrates, integrated approaches to curriculum and teaching is now fairly urgent given the traditional subject-based teaching is insufficient for tackling the new challenges we are faced with in fast-changing society. The Covid-19 pandemic has already illustrated very explicitly STEM cannot be divorced from its societal context. At a time when global numbers of people dying

from the disease is demanding not only scientific but also economic, ethical and social solutions, it is imperative to ensure that students are well equipped with skills that will enable them to cope with their everyday lives as well as their future careers. The OARS project described in the chapter provides an example where cross-subject teaching can be established with a particular focus such as argumentation. The data emerging from the project teachers' views on the collaboration are encouraging. Broadening the STEAM and STEM agendas in schools will ensure that teachers as well as students develop habits of mind that relate to certain predispositions or values that a person has, and which might include "respect for evidence and reasons" and "open-mindedness" that are critical in all school subjects. RE is particularly strong as a school subject in raising students' awareness about different value systems and thus, it can potentially provide students with a toolbox of ways of thinking that extends and enriches their understanding of STEAM.

Acknowledgment The authors acknowledge funding from the Templeton World Charity Foundation to OARS Project (Grant Number TWCF0238).

References

- Aliseda, A. (2003). Mathematical reasoning versus abductive reasoning: A structural approach. *Synthese*, 134(1–2), 25–44.
- American Association for the Advancement of Science (AAAS). (1989). *Science for all Americans*. Author.
- Bailin, S., Case, R., Coombs, J. R., & Daniels, L. B. (1999). Conceptualising critical thinking. *Journal of Curriculum Studies*, 31(3), 285–302.
- Basel, N., Harms, U., Precht, H., Weiß, T., & Rothgangel, M. (2014). Students' arguments on the science and religion issue: The example of evolutionary theory and genesis. *Journal of Biological Education*, 48(4), 179–187.
- Bazzul, J. (2016). *Ethics and science education: How subjectivity matters*. Springer.
- Beane, J. A. (1997). *Curriculum integration: Designing the core of democratic education*. Teachers College Press.
- Bencze, J. L. (Ed.). (2017). *Science and technology education promoting wellbeing for individuals, societies and environments: STEPWISE*. Springer.
- Biesta, G. J. (2015). *Beyond learning: Democratic education for a human future*. Routledge.
- Bossér, U., Lundin, M., Lindahl, M., & Linder, C. (2015). Challenges faced by teachers implementing socioscientific issues as core elements in their classroom practices. *European Journal of Science and Mathematics Education*, 3(2), 159–176.
- BouJaoude, S., Wiles, J. R., Asghar, A., & Alters, B. (2011). Muslim Egyptian and Lebanese students' conceptions of biological evolution. *Science & Education*, 20(9), 895–915.
- Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, 70(1), 30–35.
- Carter, L., Weinstein, M., & Bencze, L. (2017). Biopolitics and science education. *Cultural Studies of Science Education*, 12(4), 761–767.
- Castéra, J., & Clément, P. (2014). Teachers' conceptions about the genetic determinism of human behaviour: A survey in 23 countries. *Science & Education*, 23(2), 417–443.
- Chan, C., & Erduran, S. (2023). The impact of collaboration between science and religious education teachers on their understanding and views of argumentation. *Research in Science Education*, 53, 121–137. <https://doi.org/10.1007/s11165-022-10041-1>

- Chan, J., Fancourt, N., & Guilfoyle, L. (2020). Argumentation in religious education in England: An analysis of locally agreed syllabuses. *British Journal of Religious Education*, 43, 458–471. <https://doi.org/10.1080/01416200.2020.1734916>
- Chesky, N. Z., & Wolfmeyer, M. R. (2015). *Philosophy of STEM education: A critical investigation*. Palgrave Macmillan.
- Childs, A., Edwards, A., & McNicholl, J. (2014). Developing a multi-layered system of distributed expertise: What does cultural historical theory bring to understandings of workplace learning in school-university partnerships? In O. McNamara, J. Murray, & M. Jones (Eds.), *Workplace learning in teacher education: International practice and policy* (pp. 29–45). Springer.
- CLA: Cultural Learning Alliance. (2014). *STEM + ARTS = STEAM*. Retrieved February 13, 2017, from https://www.culturallearningalliance.org.uk/images/uploads/STEAM_report.pdf
- Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D., & Trowsdale, J. (2017). *Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: How can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?* BERA Research Commission.
- Colucci-Gray, L., Burnard, P., Gray, D., Cooke, C., Colucci-Gray, L., Burnard, P., et al. (2019). A critical review of STEAM (Science, Technology, Engineering, Arts, and Mathematics). *Oxford research encyclopedia of education*. <https://doi.org/10.1093/acrefore/9780190264093.013.398>
- Commission on Religious Education (CoRE). (2018). *Religion and world-views: The way forward*. Retrieved from <https://www.commissiononre.org.uk/final-report-religion-and-worldviews-the-way-forward-a-national-plan-for-re/>
- Cooling, T. (2012). Faith, religious education and whole school issues. In L. Philip Barnes (Ed.), *Debates in religious education* (pp. 88–97). Routledge.
- Creative Industries Federation. (2015). *Creative education agenda*. CIF.
- Cush, D. (1999). The relationships between religious studies, religious education and theology: Big brother, little sister and the clerical uncle? *British Journal of Religious Education*, 21(3), 137–146.
- Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad*. National Staff Development Council.
- Darling-Hammond, L., Hyler, M., Gardner, M., & Espinoza, D. (2017). *Effective teacher professional development*. Learning Policy Institute.
- DeBoer, G. E. (1991). *A history of ideas in science education*. Teachers College Press.
- Easton, C. (2019). Truth in science and ‘truth’ in religion: An enquiry into student views on different types of truth-claim. In B. Billingsley, K. Chappell, & M. J. Reiss (Eds.), *Science and religion in education* (pp. 123–140). Springer.
- Erduran, S. (2020). Argumentation in science and religion: Match and/or mismatch when applied in teaching and learning? *Journal of Education for Teaching*, 46(1), 129–131.
- Erduran, S. (2020a). Nature of STEM? Epistemic underpinnings of integrated science, technology, engineering, and mathematics in education. *Science & Education*, 29(4), 781–784.
- Erduran, S. (2020b). Reframing science education in light of the Covid-19 pandemic. *School Science Review*, 102(378), 38–43.
- Erduran, S., & Kaya, E. (2016). Scientific argumentation and deliberative democracy: An incompatible mix in school science? *Theory Into Practice*, 55(4), 302–310.
- Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin’s argument pattern for studying science discourse. *Science Education*, 88, 915–933.
- Erduran, S., Guilfoyle, L., Park, W., Chan, J., & Fancourt, N. (2019). Argumentation and Interdisciplinarity: Reflections from the Oxford Argumentation in Religion and Science Project. *Disciplinary and Interdisciplinary Science Education Research*, 1, 8. <https://doi.org/10.1186/s43031-019-0006-9>

- Erduran, S., Guilfoyle, L., & Park, W. (2022). Science and religious education teachers' views of argumentation and its teaching. *Research in Science Education*, 52, 655–673. <https://doi.org/10.1007/s11165-020-09966-2>
- Freathy, R., & John, H. C. (2019). Religious education, big ideas and the study of religion(s) and worldview(s). *British Journal of Religious Education*, 41(1), 27–40.
- Freathy, R., Doney, J., Freathy, G., Walshe, K., & Teece, G. (2017). Pedagogical bricoleurs and bricolage researchers: The case of religious education. *British Journal of Educational Studies*, 65(4), 425–443.
- Garet, M. S., Porter, A., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915–945.
- Ge, X., Ifenthaler, D., & Spector, J. M. (Eds.). (2015). *Emerging technologies for STEAM education: Full STEAM ahead*. Springer.
- Giannetto, E. R. A. (2009). The electromagnetic conception of nature at the root of the special and general relativity theories and its revolutionary meaning. *Science & Education*, 18(6–7), 765–781.
- Godfrey, H., & Erduran, S. (2021). Argumentation and intellectual humility: A theoretical synthesis and empirical study about students' warrants. *Research in Science and Technological Education*, 41, 1350–1371. <https://doi.org/10.1080/02635143.2021.2006622>
- Guilfoyle, L., & Erduran, S. (2021). Recalibrating the evolution versus creationism debate for student learning: Towards students' evaluation of evidence in an argumentation task. *International Journal of Science Education*, 43(18), 2974–2995. <https://doi.org/10.1080/09500693.2021.2004330>
- Guilfoyle, L., Erduran, S., & Park, W. (2020). An investigation into secondary teachers' views of argumentation in science and religious education. *Journal of Beliefs & Values*, 42(2), 190–204. <https://doi.org/10.1080/13617672.2020.1805925>
- Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th ed.). Psychology Press.
- Hand, M., & Levinson, R. (2012). Discussing controversial issues in the classroom. *Educational Philosophy and Theory*, 44(6), 614–629.
- Hannam, P., Biesta, G., Whittle, S., & Aldridge, D. (2020). Religious literacy: A way forward for religious education? *Journal of Beliefs and Values*, 41(2), 214–226.
- Hargreaves, A. (1994). *Changing teachers, changing times: Teachers' work and culture in the postmodern age*. Continuum.
- Harlen, W. (2015). *Working with big ideas of science education*. IAP.
- Haroutounian, J. (2019). Artistic ways of knowing: Thinking like an artist in the STEAM classroom. In A. J. Stewart, M. P. Mueller, & D. J. Tippins (Eds.), *Converting STEM into STEAM programs* (pp. 169–183). Springer.
- Hella, E., & Wright, A. (2009). Learning 'about' and 'from' religion: Phenomenography, the variation theory of learning and religious education in Finland and the UK. *British Journal of Religious Education*, 31(1), 53–64.
- Hookway, S. (2002). Mirrors, windows, conversations: Religious education for the millennial generation in England and Wales. *British Journal of Religious Education*, 24(2), 99–110.
- Jackson, R. (1997). *Religious education: An interpretive approach*. Hodder & Stoughton.
- Jackson, R. (2004). *Rethinking religious education and plurality*. Routledge Falmer.
- Jawoniyi, O. (2015). Religious education, critical thinking, rational autonomy, and the child's right to an open future. *Religion & Education*, 42(1), 34–53.
- Jimenez-Aleixandre, M. P., Rodriguez, A., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, 84(6), 757–792.
- Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the family resemblance approach can be transformed for science curriculum analysis on nature of science. *Science & Education*, 25(9–10), 1115–1133.
- Kuhn, T. S. (1962). *The structure of scientific revolutions*. University of Chicago Press.

- Lambeth Council. (2015). *Lambeth agreed syllabus for religious education*. Lambeth Council. 790
- Lantz-Andersson, A., Lundin, M., & Selwyn, N. (2018). Twenty years of online teacher communi- 791
ties: A systematic review of formally-organized and informally-developed professional learn- 792
ing groups. *Teaching and Teacher Education*, 75, 302–315. 793
- Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific 794
issues. *International Journal of Science Education*, 28(10), 1201–1224. 795
- Lewis, A. L. (2015). Putting the “H” in STEAM: Paradigms for modern liberal arts education. 796
In X. Ge, D. Ifenthaler, & J. M. Spector (Eds.), *Emerging technologies for STEAM education* 797
(pp. 259–275). Springer. 798
- Mansour, N. (2015). Science teachers’ views and stereotypes of religion, scientists and scientific 799
research: A call for scientist–science teacher partnerships to promote inquiry-based learning. 800
International Journal of Science Education, 37(11), 1767–1794. 801
- Matthews, M. R. (Ed.). (2009). *Science, worldviews and education*. Springer. 802
- McDonald, C. V. (2017). Exploring representations of nature of science in Australian junior sec- 803
ondary school science textbooks: A case study of genetics. In C. V. McDonald & F. Abd-El- 804
Khalick (Eds.), *Representations of nature of science in school science textbooks: A global* 805
perspective (pp. 98–117). Routledge. 806
- McKinney, S., Hall, S., Lowden, K., Smith, M., & Beaumont, P. (2014). Searching for meaning – 807
Science and religious education teachers collaborating in interdisciplinary teaching and learn- 808
ing. *Scottish Educational Review*, 46(1), 32–47. 809
- National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 810
Committee on Science, Engineering, and Public Policy & Committee on Facilitating 811
Interdisciplinary Research. (2005). *Facilitating interdisciplinary research*. The National 812
Academies Press. 813
- National Art Education Association (NAEA). (2017). *Position statement on STEAM education*. 814
Alexandria, VA. Retrieved July 2, 2020, from [https://www.arteducators.org/advocacy-policy/](https://www.arteducators.org/advocacy-policy/articles/552-naea-position-statement-on-steam-education) 815
[articles/552-naea-position-statement-on-steam-education](https://www.arteducators.org/advocacy-policy/articles/552-naea-position-statement-on-steam-education) 816
- Nesta. (2014). *Fix the pipeline for STEAM talent in the creative economy* Retrieved February 23, 817
2017, from <http://www.nesta.org.uk/blog/fix-pipeline-steam-talent-creative-economy> 818
- Norfolk County Council. (2012). *The Norfolk agreed syllabus for religious education 2012*. 819
Norfolk County Council. 820
- Nussbaum, M. C. (2010). *Not for profit: Why democracy needs humanities*. Princeton 821
University Press. 822
- OECD. (2017). *PISA 2015 assessment and analytical framework: Science, reading, mathematic,* 823
financial literacy and collaborative problem solving (Revised edn.). OECD Publishing. 824
Retrieved July 1, 2020, from <https://doi.org/10.1787/19963777> 825
- OECD. (2019). *Fostering students’ creativity and critical thinking*. OECD Publishing. Retrieved 826
July 2020 from [https://www.oecd.org/education/fostering-students-creativity-and-critical-](https://www.oecd.org/education/fostering-students-creativity-and-critical-thinking-62212c37-en.htm) 827
[thinking-62212c37-en.htm](https://www.oecd.org/education/fostering-students-creativity-and-critical-thinking-62212c37-en.htm) 828
- OECD. (2020). *PISA 2024 Strategic Vision and Direction for Science*. Retrieved June 30, 2020, from 829
<https://www.oecd.org/pisa/publications/PISA-2024-Science-Strategic-Vision-Proposal.pdf> 830
- Oxford University Press. (n.d.). World-view. *Oxford English Dictionary*. Retrieved July 2, 2020, 831
from <https://www.oed.com/view/Entry/230262?redirectedFrom=world+view#eid13857122> 832
- Park, W., Wu, J.-Y., & Erduran, S. (2020a). The nature of STEM disciplines in the science educa- 833
tion standards documents from the USA, Korea and Taiwan: Focusing on disciplinary aims, 834
values and practices. *Science & Education*, 29(4), 899–927. 835
- Park, W., Yang, S., & Song, J. (2020b). Eliciting students’ understanding of nature of science with 836
text-based tasks: Insights from new Korean high school textbooks. *International Journal of* 837
Science Education, 42(3), 426–450. 838
- Park, W., Erduran, S., & Guilfoyle, L. (2022). Secondary teachers’ instructional practices on argu- 839
mentation in the context of science and religious education. *International Journal of Science* 840
Education, 44(8), 1251–1276. <https://doi.org/10.1080/09500693.2022.2074565> 841
- Pedemonte, B. (2007). How can the relationship between argumentation and proof be analysed? 842
Educational Studies in Mathematics, 66(1), 23–41. 843

- Ratcliffe, M., & Millar, R. (2009). Teaching for understanding of science in context: Evidence from the pilot trials of the twenty first century science courses. *Journal of Research in Science Teaching*, 46(8), 945–959.
- Reed, E. D., Freathy, R., Cornwall, S., & Davis, A. (2013). Narrative theology in religious education. *British Journal of Religious Education*, 35(3), 297–312.
- Sadler, T. D., Amirshokooi, A., Kazempour, M., & Allspaw, K. M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching*, 43(4), 353–376.
- Schreiner, P. (2009). The religious, moral and spiritual dimensions of education: National, regional and international constitutional and legal frameworks. In M. de Souza, G. Durka, K. Engebretson, R. Jackson, & A. McGrady (Eds.), *International handbook of the religious, moral and spiritual dimensions in education. International handbooks of religion and education* (Vol. 1). Springer.
- Sharma, A. (2012). Global climate change: What has science education got to do with it? *Science & Education*, 21(1), 33–53.
- Skeie, G. (2009). Plurality and pluralism in religious education. In M. de Souza, G. Durka, K. Engebretson, R. Jackson, & A. McGrady (Eds.), *International handbook of the religious, moral and spiritual dimensions in education* (pp. 307–319). Springer.
- Thagard, P., & Findlay, S. (2010). Getting to Darwin: Obstacles to accepting evolution by natural selection. *Science & Education*, 19(6–8), 625–636.
- The Religious Education Council of England and Wales (REC). (2013). *A curriculum framework for religious education in England (October 2013)*. https://www.religiouseducationcouncil.org.uk/wp-content/uploads/2017/09/RE_Review_Summary.pdf
- The Royal Society Science Policy Centre. (2014). *Vision for science and mathematics education*. The Royal Society. Retrieved June 30, 2020, from <https://royalsociety.org/-/media/education/policy/vision/reports/vision-full-report-20140625.pdf>
- Walton, D. (1996). *Argumentation schemes for presumptive reasoning*. Erlbaum Press.
- Walton, D. N. (2001). Abductive, presumptive and plausible arguments. *Informal Logic*, 21, 141–169.
- White, J. (2004). Should religious education be a compulsory school subject? *British Journal of Religious Education*, 26(2), 151–164.
- Wong, V., Dillon, J., & King, H. (2016). STEM in England: Meanings and motivations in the policy arena. *International Journal of Science Education*, 38(15), 2346–2366.
- Wright, A. (1993). *Religious education and the secondary school: Prospects for religious literacy*. David Fulton Publishers.
- Yacoubian, H. A., & Hansson, L. (Eds.). (2020). *Nature of science for social justice*. Springer.
- Yakman, G., & Lee, H. (2012). Exploring the exemplary STEAM education in the US as a practical educational framework for Korea. *Journal of the Korean Association for Science Education*, 32(6), 1072–1086.
- Yeh, Y., Erduran, S., & Hsu, Y. S. (2019). Investigating coherence on nature of science in the science curriculum documents: Taiwan as a case study. *Science & Education*, 28(3–5), 291–310.
- Zack, V., & Graves, B. (2001). Making mathematical meaning through dialogue: “Once you think of it, the Z minus three seems pretty weird”. *Educational Studies in Mathematics*, 46(1), 229–271.

Sibel Erduran is a Professor of Science Education at University of Oxford, United Kingdom where she works as the Director for Research in the Department of Education. She is the Editor-in-Chief of *Science & Education* and an Editor for *International Journal of Science Education*. She has served as the President of ESERA and worked as an elected member on the Executive Boards of NARST and IHPST. She has held Visiting Professorship positions at universities in Sweden, Turkey, Taiwan and Norway, and delivered keynote speeches at international conferences across the world including in Argentina, China, Singapore, South Africa, and United Arab

Emirates. Her research interests include the integration of nature of science and epistemic practices in science education. She has been the Principal Investigator of research projects funded by the Wellcome Trust, Templeton World Charity Foundation and Science Foundation Ireland among others. Her research on argumentation has received awards from NARST and EASE. She received her Ph.D. in Science Education and Philosophy from Vanderbilt University; MSc in Food Chemistry from Cornell University; and BA in Biochemistry/Chemistry from Northwestern University, USA.

Liam Guilfoyle is a Lecturer in Science Education at the Department of Education, University of Oxford, UK. His research interests generally centre around (1) teachers' engagement with and in research, and (2) epistemic beliefs, cognition, and practices within and across disciplines. He is currently Course Director for the MSc in Learning and Teaching which supports practicing teachers to become evidence-informed practitioners through engagement with/in research in their educational contexts. He also leads the Advanced Qualitative Research course for DPhil Students across the Social Sciences Division at the University of Oxford. His research has appeared in *Teaching and Teacher Education*, *International Journal of Science Education*, *British Journal of Educational Technology*, *Disciplinary and Interdisciplinary Science Education Research* and *Journal of Education for Teaching*. He has worked on projects supported by the Irish Research Council, Templeton World Charity Foundation, European Commission, and Science Foundation Ireland. He holds a BSc.Ed. in Biological Sciences and Physics, and a PhD in Education from the University of Limerick, Ireland.

Wonyong Park is a Lecturer in Science Education at the Southampton Education School, University of Southampton, UK. His research interests include the history, philosophy and nature of science, and the role of science and STEM education in disaster justice and resilience. His research uses interdisciplinary approaches that cut across science and other subjects such as history, citizenship and religious education. His research has appeared in *International Journal of Science Education*, *Science & Education*, *Asia Pacific Education Review*, *Research in Science Education*, *Cultural Studies of Science Education*, *Journal of Curriculum Studies* and *Educational Philosophy and Theory*. He has co-edited special issues of *International Journal of Science Education* and *Science & Education*. His work has been supported by the Economic and Social Research Council, the National Science Foundation, and the UNESCO Regional Bureau for Science and Culture in Europe. He holds a BSc and MSc in Physics Education from Seoul National University, Korea, and a DPhil in Science Education from the University of Oxford, UK.

Author Queries

Chapter No.: 12 0005771220

Queries	Details Required	Author's Response
AU1	As per style "Author biography" moved to chapter end please confirm.	
AU2	UK Cultural Learning Alliance and Nesta (2017), Toulmin (1958), Fancourt (2013, 2015), Smart (1989), Hannam and Biesta (2019), NGSS Lead States (2013), DfE (2015), Erduran and Dagher (2014), Erduran et al. (2020) have been cited in text but not given in the reference list. Please provide the details in the list or delete the citations from the list, if applicable.	
AU3	Toulmin (1958), DfE (2015), NGSS Lead States (2013), NAS et al. (2005), Fancourt (2013), Fancourt (2015), Smart (1989), Hannam and Biesta (2019) have been cited in text but not given in the reference list. Please provide the details in the list or delete the citations from the list, if applicable.	
AU4	Chan and Erduran (2013) has been changed to Chan and Erduran (2023) as per the reference list. Please confirm.	
AU5	References "CLA: Cultural Learning Alliance (2014), Guilfoyle et al. (2020), Wong et al. (2016)" were not cited anywhere in the text. Please provide in text citation or delete the reference from the reference list.	